Ocean Data Assimilation for Coupled Models

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Award #: N0001499WX30268

LONG-TERM GOALS

The long-term goal of this project is to improve our ability to analyze and predict the upper ocean/lower atmosphere environment, using sophisticated techniques that can exploit data from all available sources. This ability is fundamental to meeting DOD's needs for real-time analysis and improved air/sea simulation and prediction on a variety of scales, including mesoscale to tactical scale support in littoral environments and on the battlefield. To meet these needs, the Naval Research Laboratory is developing the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), and has already transitioned the atmospheric prediction system and surface ocean analysis components to operations.

OBJECTIVES

The objective of this particular project is to develop the globally-relocatable, three-dimensional multivariate ocean data analysis component of COAMPS to provide a capability that will 1) provide the best possible initial conditions for the mesoscale ocean forecast model and 2) provide accurate lower boundary conditions for the atmospheric forecast model. The emphasis is on the development of a complete ocean data assimilation capability, where oceanographic data from a variety of sources are assimilated into an ocean forecast model at regular intervals in a dynamically consistent fashion. The ocean data analysis component must be able to analyze all conventionally available data sources, plus incorporate new data such as upper ocean velocity observations from drifter tracks and HF radar.

APPROACH

Plans for developing the next-generation ocean data assimilation system include leveraging the experience of both the atmospheric and oceanographic communities. Most current ocean analysis systems are based on the optimum interpolation (OI) methodology, which is a desirable statistical interpolation technique used successfully in meteorological systems for twenty years. However, the existing ocean analysis systems often use climatology as a background field, are univariate (in temperature) and two-dimensional, with vertical coupling of the various levels provided only through the use of statistically derived synthetic profile observations. If such a system is used to initialize an ocean forecast model, additional steps must be taken to initialize the model's velocity field. Our

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 1999		**00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Ocean Data Assimilation for Coupled Models	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Naval Research Laboratory,Monterey,CA,93943-5502	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

project is expanding the univariate OI approach to a fully multivariate, three-dimensional OI ocean data assimilation capability (3D MVOI), where adjustments to the ocean's mass field will be correlated with adjustments to the ocean's flow field, and a short-term model forecast will provide the analysis background field. This capability will set the stage for utilizing even more sophisticated techniques in the future, such as three-dimensional and four-dimensional variational data assimilation. A key ingredient of this research is to investigate how to properly specify the various statistical input parameters that determine the ultimate skill of the analysis. As we extend the analysis capability to assimilate multiple variable types from a number of different sources, new quality control techniques must be developed for those observations and the appropriate observation errors must be evaluated. We will progress from loose to tight coupling between the ocean and the atmospheric systems, and all development will ultimately be tested within the structure of the entire coupled prediction system. In addition, we will ensure that the software developed is fully compatible with other existing and planned components of COAMPS, thereby providing a seamless depiction of the air/sea environment within a single package.

WORK COMPLETED

The COAMPS Ocean Data Assimilation (CODA) three-dimensional multivariate optimum interpolation (3D MVOI) analysis was fully incorporated as an integral part of COAMPS during FY99. A full 3D MVOI ocean analysis can now be performed on one or more of the COAMPS nested grid by appropriate specification of the COAMPS namelist parameters. The 2D analysis capabilities for SST and sea ice as lower boundary conditions for the atmospheric model, installed in COAMPS during FY98, have been maintained in the CODA 3D MVOI update to the COAMPS software system.

As a major step in achieving commonality between CODA and the Modular Ocean Analysis System (MODAS) developed at NRL Stennis, CODA now assimilates altimeter sea surface height (SSH) data, in the form of MODAS synthetic temperature and salinity profiles, as supplemental observations to the real-time database. In addition, the MODAS 2.1 databases allowed for the development of new capabilities in the CODA analysis, as described below.

The MVOI correlation functions in CODA were updated to allow the horizontal correlation length scales to vary with position and the vertical correlation length scales to vary with time, which is an important feature that makes the MVOI easily adaptable to various grids in multiple locations.

In addition, the background error variances in CODA have been updated to allow for time dependence and to vary in the vertical. This type of time-dependency is common in four-dimensional variational analysis methodologies.

RESULTS

The MODAS 2.1 databases contain a complete variability product that permits sophisticated quality control (QC) procedures to be applied to the synthetic BTs prior to insertion into the analysis. Experience has shown that QC of this data is quite important in preventing bulls-eyes or other unrealistic features from appearing in the analyzed fields. Also, residual errors of the regression models used to compute the synthetic profiles are stored in the MODAS 2.1 databases. The residual errors are time and space dependent and residual errors are at a minimum where the relationship between SSH,

SST and temperature at depth is well-defined (e.g. western boundary currents). In a CODA analysis, residual errors are combined with errors in the SST and SSH predictor fields to prescribe synthetic profile observation errors, which allows the synthetic profiles to be more accurately weighted relative to the other types of observations that are available to the analysis. The MODAS 2.1 databases were also incorporated in the complex QC procedures for profile observations. Synthetic profiles and static climatology profiles are generated at XBT and PALACE float locations and sampling times using the MODAS 2.1 databases. The MODAS 2.1 variability product is used to normalize the synthetic, climatological and observed profile increments to determine if the observed profile contains a gross error.

Preliminary efforts to define the statistical input parameters for the analysis compute the background horizontal correlation length scales in CODA proportional to the first baroclinic Rossby radius of deformation, using the global climatological atlas recently computed by Chelton et al. (1998). The horizontal correlation length scales vary from less than 10 km at the poles to over 200 km in the tropics, which extends the influence of a given observation in areas of lower variability. The vertical correlation length scales are a function of mixed layer depth in CODA, where mixed layer depth is computed from the first guess temperature and salinity fields prior to the 3D MVOI analysis using a change-in-density criterion. Vertical correlation scales are a minimum at the base of the mixed layer, which prevents surface observations from influencing the analysis below the mixed layer.

Error variances are computed for geopotential, temperature and salinity at all analysis levels from observation-minus-forecast differences summed over the previous 120 update cycles. The background error variances are used to normalize observation errors in a CODA analysis. Typically, background error variances are large when CODA is cold-started from climatology, resulting in observations carrying more weight in the analysis. Eventually, after several update cycles, the background error variances become smaller and the observations are less heavily weighted in the analysis.

CODA 3D MVOI analyses with the various upgrades described above has been successfully executed in each of the four COAMPS geographic domains run operationally at FNMOC. These areas include the Sea of Japan, Mediterranean Sea, western North Atlantic, and a tropical region centered over Mexico and Central America. No problems have been encountered cycling CODA using the previous analysis as a background field, and the analyzed fields are consistent with known oceanographic circulation patterns in each of the geographic domains.

IMPACT/APPLICATIONS

Multivariate analysis of mass and velocity in the ocean is new. In an ocean MVOI analysis, mass and velocity are consistent with simple linear dynamic constraints, and the constraints are built right into the algorithm. It is likely that a cold-start initialization of an ocean forecast model is enhanced from such completely specified, dynamically consistent, background fields. Long spin-up runs of a regional ocean model thus may not be necessary, thereby allowing the ocean modeling and assimilation components of COAMPS to be easily and quickly re-located in a time of crisis, similar to what is now possible for the atmospheric components of COAMPS. Enhanced ability to define the littoral battlespace environment through the use of a coupled air/ocean-analysis/model system will provide Navy forces with a unique capability to exploit the environment to their tactical advantage.

TRANSITIONS

The CODA surface analysis has been transitioned via a related 6.4 project (Ocean Data Assimilation for COAMPS, PE 0603207N, SPAWAR PMW-185) and is now operational as part of the COAMPS atmospheric prediction system. That system is executed at Fleet Numerical Meteorology and Oceanography Center (FNMOC) for several regional areas around the globe. This same version of COAMPS comprises part of the Tactical Atmospheric Mesoscale System/Real- Time, which is currently being run on-scene in demonstration mode at the San Diego and Bahrain METOC centers, as well as by several other defense-related customers. The CODA 3D MVOI is installed in the COAMPS developmental software configuration management system at NRL Monterey and was transitioned to FNMOC in FY99. An OPSTEST of the 3D oceanographic MVOI capability of COAMPS at FNMOC is planned for 1Q FY00 as a replacement for the existing ocean analyses. All developmental and operational users of COAMPS routinely utilize CODA. These users include the Navy operational centers, Navy Laboratories, the National Laboratories, and several universities.

RELATED PROJECTS

This project complements: 1) several ongoing efforts at NRL Monterey focusing on atmospheric/aerosol mescoscale model development (BE 35-2-18), atmospheric data assimilation (BE 35-2-19), and air/sea interaction studies (BE033-03-45; 2) the ongoing ocean modeling and data assimilation efforts at NRL Stennis; and 3) the joint NRL (SSC/MRY) Navy Coastal Ocean Model (NCOM) development effort (ONR Award N0001499WX30265), which directly supports the ocean forecast component of COAMPS.